Iran. J. Ichthyol. (June 2014), 1(2): 114–120

P-ISSN: 2383-1561; E-ISSN: 2383-0964
http://www.ichthyol.ir

Received: April 06, 2014
Accepted: May 29, 2014

Morphological responses of *Capoeta gracilis* and *Alburnoides eichwaldii* populations (Cyprinidae) fragmented due to Tarik Dam (Sefidrud River, Caspian Sea basin, Iran)

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Abstract: This study was conducted to evaluate the morphological responses of two different species including *Capoeta gracilis* and *Alburnoides eichwaldii* due to construction of the Tarik dam in the Sefidrud River using geometric morphometric technique. For this purpose, a total of 80 specimens of *C. gracilis* and 60 specimens of *A. eichwaldii* were collected from upstream and down-stream of dam. The left sides of specimens were photographed and14 and 18 landmark-points were digitized on 2D pictures of and *C. gracilis* and *A. eichwaldii*, respectively. The landmark data were submitted to GPA to remove non-shape data, analyzed by discriminate functional analysis and Ttest hotelling. The results showed no differences between the upstream and downstream populations of *C. gracilis*, but a significant difference found in *A. eichwaldii* in terms of body shape. The observed differences were related to head, snout, caudal peduncle regions and eye diameter that could be an adaptation to altered habitat and hydrological conditions of upstream and downstream due to damming. Different response of two studied species displayed that fishes can respond in different way to anthropogenic modifications of riverine ecosystem.

Keywords: *Capoeta gracilis*, *Alburnoides eichwaldii*, Geometric morphometrics, Sefidrud.

Introduction

Dams represents one of the most disruptive anthropogenic modifications of riverine ecosystems worldwide (Graf 1999). Dam construction is the prominent case of human manipulation in river ecosystems affecting its fauna (Craig 2001). They impose fundamental changes to natural landscapes by transforming rivers into reservoirs (Haas et al. 2010), creating new ecological and evolutionary challenge for aquatic organisms (Baxter 1977). Subsequently, this new environment can cause some variations in the body shape of aquatic organisms, because they have to respond to the absence of flow (Lowe-McConnell 1987; Vogel 1994). Different flow conditions between upstream and downstream of rivers may be led genetic and morphological differences among populations (McAllister et al. 2001; Langerhans & Reznick 2010). Construction of dams also affects fish movements, which may conduct to differentiation of populations (Meldgaard et al. 2003; Heidari et al. 2013). It has been suggested that fragmentation of river ecosystems may result in the conversion of migration patterns between fish populations (Craig 2001; Jager et al. 2001; Heidari et al. 2013).

Body shape differences not only reflect genetic characteristics of populations but also environmental parameters (Guill et al. 2003). Morphological changes induced by environmental factors can help to better understanding of the phenotypic plasticity process as result of induced factors (Mohadasi et al. 2013). Geometric morphometric (GM) is used to quantify the body shape of biological structures (Bookstein 1991) and have been applied to

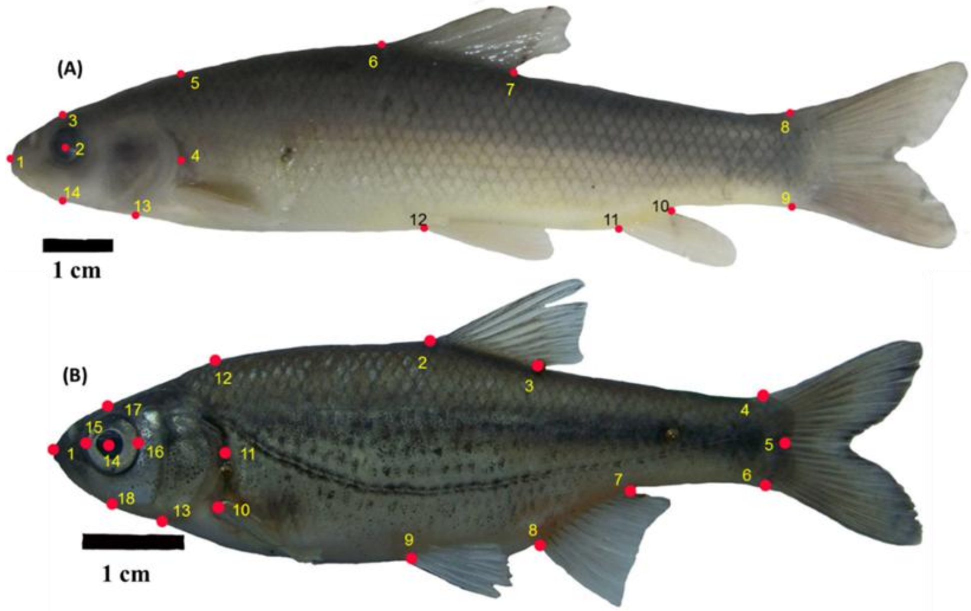

Fig.1. Defined landmark points to extract the body shape of (A) *Capoeta gracilis*. 1. Snout tip; 2. Center of eye; 3. Dorsal edge of the head perpendicular to eye center; 4. Point of maximum extension of operculum on the lateral profile; 5. Dorsal edge of body perpendicular to lankmark number 4; 6. Anterior point of dorsal fin base; 7. Posterior point of dorsal fin base; 8. Antrodorsal point of caudal fin; 9. Aneroventral point of caudal fin; 10. Posterior insertion of the anal fin; 11. Anterior insertion of the anal fin; 12. Insertion of the pelvic fin; 13. Insertion of the operculum on the ventral edge; 14. Ventral edge of the head perpendicular to eye center and (B) *Alburnoides eichwaldii*. 1. Snout tip; 2. Anterior point of dorsal fin base; 3. Posterior end of dorsal fin base; 4. Antero-dorsal point of caudal fin; 5. Posterior end of body lateral line; 6. Antero-ventral point of caudal fin; 7. Posterior end of anal fin base; 8. Anterior end of anal fin base; 9. Anterior insertion of the pelvic fin; 10. Anterior point of the pectoral fin; 11. Posterior end of opercular gill slit; 12. Insertion of the operculum on the ventral edge; 14. Center of eye; 15. Anterior end of eye; 16. Posterior end of eye; 17. Dorsal edge of the head perpendicular to eye center; 18. Ventral edge of the head perpendicular to eye center.

distinguish and differentiate populations based on morphological characters (Turan 1999: Loy et al. 1999). Landmark-based GM uses the landmark coordinates to extract the shape data (Zelditch et al. 2004) and has been considered as a useful tool to assess phenotypic plasticity. This method quantifies changes in shape, and patterns of morphometric variations within and between groups (Marcus et al. 1996; Khataminejad et al. 2013; Eagderi & Kamal 2013)

Capoeta gracilis Keyserling, 1861 (formerly known as *Capoeta capoeta gracilis*) and *Alburnoides eichwaldii* De Filippii, 1863 as our study models, are adaptable species to various environmental conditions. *Capoeta gracilis* is found in the Southern Caspian Sea basin (Abdurakhmanov 1962) and a predominant fish of the Sefidrud River (Heidari et al. 2013). *Alburnoides eichwaldii* is distributed in small streams and rivers of Iran (Esmaeili et al. 2010; Coad 2014). This species along with *C. gracilis* are the most abundant species inhabiting rivers of the Caspian Sea basin (Heidari et al. 2013; Coad 2014).

The Tarik dam is constructed in 1968, in intersection of the Siahrood and Sefidrud Rivers (36◦ 59′ E, 49◦ 34′N) in the Guilan Province (North of Iran). Heidari et al. (2013) studied the body shape variation of *C. gracilis* in up- and downstream populations of the Tarik dam collected in winter and demonstrated significant differences in terms of body shape among the isolated populations. In the present study, we examined (1) whether similar morphological responses can be observed in another species i.e. *Alburnoides eichwaldii* and (2) since this river ecosystems show a coarse grained environment and also the member of the genus *Capoeta* with a fusiform body shape suggested to be a generalists fish species in terms of body shape inhabiting in various lentic and lotic habitats, the observed effect

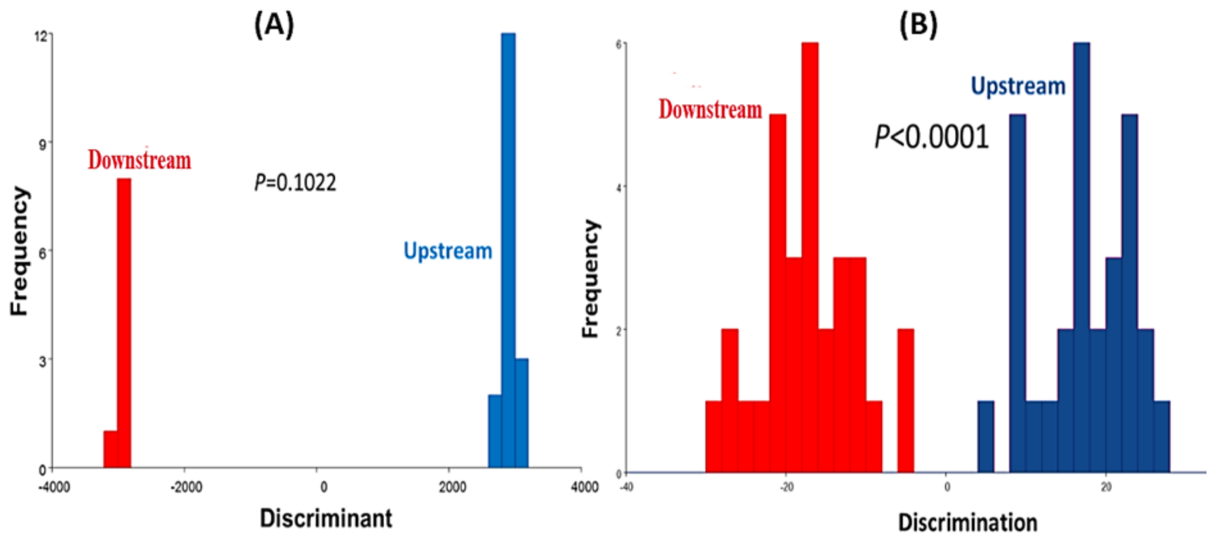

Fig.2. Graphs of the Discriminant Function Analysis of the relative warp scores of body shape of (A) *Capoeta gracilis* and (b) *Alburnoides eichwaldii* between upstream and downstream populations.

of dam construction on the body shape of *C. gracilis* can be effected by changing river properties. Hence, this study was conducted to investigate the impact of the Tarik dam on the morphological characteristics of two different species including *C. gracilis* and *A. eichwaldii* collected in summer in which hydrological characteristics are different than that of winter (see Heidari et al. 2013) using geometric morphometrics technique.

Materials and methods

In total 80 specimens of *C. gracilis* and 60 specimens of *A. eichwaldii* were collected from upstream and downstream of the Tarik dam in June 2013 by electrofishing. The specimens were anaesthized, then fixed into buffered 10% formaldehyde at the sampling site and transferred to the laboratory. The specimens of similar size were selected to remove allometric differences and also the selected specimens had no deformity in terms of body shape. The left sides of specimens were photographed using a copy-stand equipped to a digital camera (Kodak with 6 MP resolution).

To extract body shape in Landmark-based GM method, 14 and 18 landmark-points were digitized using tpsDig2 software (version 2.16) on left sides of *C. gracilis* and *A. eichwaldii*, respectively (Figs. 1 a, b). Then landmark data were submitted to a generalized procrustes analysis (GPA) to remove non-shape data including scale, direction and position. The discriminate functional analysis (DFA) and Ttest hotelling (Hotelling's T test) was accomplished to investigate power of distinction among the populations by MorphoJ (version 1.01) and Past (version2.10) softwares. The consensus shape of the upstream and downstream population of each species was visualized using the wireframe graphs to compare their shape differences.

Results

DFA/ Ttest hotelling showed no differences between the upstream and downstream populations of *C. gracilis* in terms of body shape (p<0.102; Fig. 2a), whereas there was a significant difference between upstream and down-stream populations of *A. eichwaldii* (p=0.0001; Fig. 2b).

The results of visualization by wireframe graph revealed that *C. gracilis* in upstream have larger head and deeper body than those of down-stream but different was not significant (Fig. 3a). In *A. eichwaldii*, the observed differences were related to head, snout, caudal peduncle regions and eye diameter (Fig. 3b). The upstream population had smaller head with shorter snout, a narrower caudal

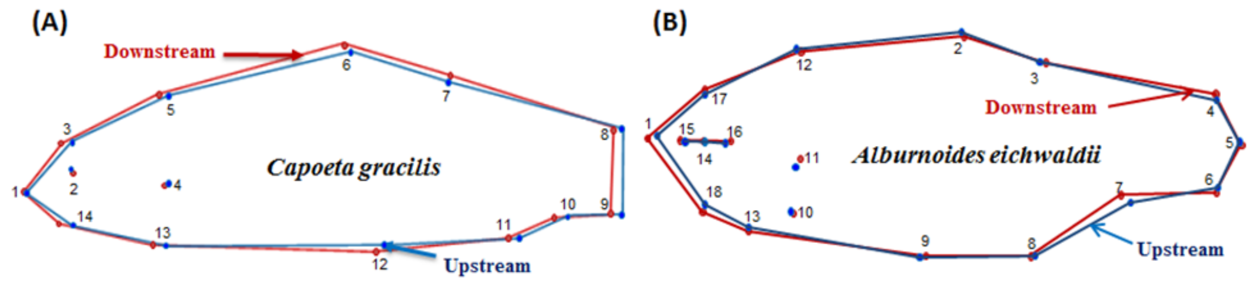

Fig.3. Wireframe graph showing the consensus body shape differences of upstream and downstream populations of (A) *Capoeta gracilis* and (b) *Alburnoides eichwaldii.*

peduncle depth and smaller eye diameter (Fig. 3b).

Discussion

Fish morphology indicates their adaptation to life history and environmental parameters (Knouft 2003) i.e. their morphological characteristics such as streamline or deep body shapes can reflect their habitat properties (Webb 1982; Winemiller 1992). A species maybe inhabit in different ecosystems (Ehlinger & Wilson 1988) and this can be led to different body shape resulting from different environmental conditions (Robinson & Wilson 1996; Prolux & Magnan 2004; Svanback & Eklov 2006). The upstream population *A. eichwaldii* displayed smaller head, shorter snout and less caudal peduncle depth in compared to those of the downstream populations. Yamamoto et al. (2004) pointed out that habitat fragmentation caused by damming resulted different body shape in white-spotted charr, *Salvelinus leucomaenis* populations 20 years after the construction of the dam. Habitat type and hydrological properties of riverine system have been reported as effective factors on the body shape (Dadikyan 1973; Eagderi et al. 2013). Hence, differences in the current regime and habitat type resulted by construction of the Tarik dam can be considered as factors influenced the body shape differences in *A. eichwaldii.*

Different snout shapes in the upstream and down-stream may be due to different available food sources. Variation in mouth and head areas reflects differences in feeding behavior including food type and feeding direction (Langerhans et al. 2003). Larger head and long snout is an advantage for fishes feeding in current water (Winemiller 1992; Moyle & Cech 2000) as seen in downstream population of *A. eichwaldii.* Also, the deeper caudal peduncle can enhance swimming capability (Fisher & Hogan 2007) by accelerating movement (Webb 1982). This feature may be advantage for downstream population to obtain food and escape from predators.

Despite of *A. eichwaldii*, the upstream and down-stream populations of *C. gracilis* showed no significant differences in terms of body shape. These contradictory results may be linked to species properties. Since, *C. gracilis* is a species with generalist body shape, may be not responded to habitat transformation or fragmentation as result of damming in short term. In addition, species with narrow distribution capacity such as *A. eichwaldii* may be affected more than those with wider distribution capacity such as *C. gracilis* due to habitat defragmentation (Fahrig 2003). *Capoeta gracilis* found in various freshwater habitats including lakes and rivers with pebble, sandy beds and aquatic plants (Valipor 2004) and rapid and slow flow rivers (Turan 2008). Also, this species is eurytherm and resistant to pollution (Coad 2014).

The findings of this study differ from those of Heidari et al. (2013) that showed morphological differences between the up and downstream of *C. gracilis* populations due to the Manjil and Tarik dams (Sefidrud River, southern Caspian Sea basin). This difference can be related to the type of dam, the time that the population fragmented and sampling period. The long-term isolation of populations and

interbreeding may lead to morphometric variations between populations, and provides a basis for population differentiation (Heidari et al. 2013) and this could be an answer in the case of Manjil Dam. In addition, the hydrological characteristics of rivers vary on time scales much less (Padilla & Adolph 1996) and fishes expected to response to fine-grained environmental variation even in those with generalist phenotype such as *C. gracilis* that bears a fusiform body shape (Ruehl & DeWitt 2005).

In summary, this study showed difference in the body shape of fishes as result of anthropogenic modifications of riverine ecosystems (Lattuca et al. 2007). This modification by transforming rivers into reservoirs, create new ecological and evolutionary challenge for inhabited fishes. Also, the results displayed different response of two species i.e. *C. gracilis* and *A. eichwaldii* in terms of body shape that may be related to fish species i.e. fishes can respond in different way to anthropogenic modifications of riverine ecosystem. Hence, different effects of habitat isolation means that all fish species do not threatened by habitat defragmentation.

Acknowledgments:
This study was financially supported by University of Tehran.

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